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Development of low loss waveguide filters for radio-astronomy applications

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HIGHLIGHTS

- In this paper the modeling, fabrication and experimental characterization of wideband band-pass filters operating in W-band (75-110 GHz) is presented.
- Two different prototypes were fabricated using an accurate electroforming machining technique. One should note the low level of insertion loss reported of about 0.4 dB within the band-pass, whichis a critical parameter for low-noise receivers.
- In addition, the presented designs fulfill the stringent specifications and can be used in radio-astronomy receivers to select the desired entire spectral band.

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ABSTRACT

In this paper the modeling, fabrication and experimental characterization of a wideband band-pass filter operating in W-band (75–110 GHz) is presented. This new high-performance waveguide filter can have several potential applications and will particularly be relevant in radio-astronomy receivers. The classical direct coupled cavity-based synthesis is first used. Then, an efficient full-wave analysis based on the mode matching technique is carried out, leading to a tenth order all-pole filter design. Two different prototypes were fabricated using an accurate electroforming machining technique. A good agreement between simulation and measurements is obtained with negligible frequency shift and 15 dB return loss level. One should note the low level of insertion loss reported of about 0.4 dB within the band-pass, which is a critical parameter for low-noise receivers.

1. Introduction

Radio and millimeter wave receivers for astronomy [1] are in need of the highest instrumental transmission in order to reach a high sensitivity and of a very stringent out-of-band spectral rejection to avoid signal contamination by other sources. This is particularly relevant for direct detectors (such as bolometers), which are sensitive to a very large EM spectrum. So far, the spectral definition of the receivers using this type of detectors is achieved by using a combination of quasi-optical interference filters [2], each of them being either a low-pass, high-pass or band-pass filter. A maximum transmission of only 80% can be reached with this technology. When used in conjunction with feed horns, the high-pass cut-off of the horn waveguide (circular smooth of corrugated) [4,5] can be used to remove one or more interference filter. However, in this case, the interference filters located in front of the horn aperture will degrade the beam shape performance, which is a crucial issue for instruments dedicated to the study of the Cosmic Microwave Background. Solutions to avoid these effects such as a back-to-back horn configuration [4] can be adopted but will result in a cumbersome arrangement. Nevertheless, most of the instruments will remain with optical filters in front of the horn and will need to deal with the systematic effects [3,6].

A different approach used at low frequency is based on superconductor filters in planar technology (mainly microstrip) [7]. Superconductors at low microwave frequency present low loss. In addition, planar technology is more compact and less bulky than waveguides. Nevertheless, the main limitation of superconductor filters is that the device should work at low temperature. Moreover, microstrip filters are being developed for higher frequencies (100 and 150 GHz [8]) but so far no data on their losses have been reported.

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Table 1
Specifications of the filter.

Band-pass	From 85 to 105 GHz
Return loss	17 dB
Insertion loss	As low as possible
Rejection	>30 dB below 83 GHz
	>30 dB above 108 GHz

Waveguide filters have been extensively used in the domain of communications and are now being used for radio-astronomy receivers. Waveguide band-pass filters for radio-astronomy applications have been designed recently [9,10] and used as part of a polarimetric receiver at Ka-band (26.5–40 GHz). At millimeter wave band and above, waveguide technology is the main alternative for passive devices due to its intrinsic low loss. Different band-pass filters have been presented at W-band for both narrow and wide band and using different fabrication processes. In Ref. [11] a waveguide filter at 94 GHz based on the E-plane metal inset is presented. The metal inset can be accurately machined using laser ablation. However, this geometry is not suitable for wide band filters since fragile thin metal inset should be used to implement very high couplings values between resonant cavities (particularly the first and last coupling). Three different narrow band filters and multiplexer are presented in Ref. [12], all machined by a low cost milling technique. In Ref. [13] an elliptic response filter for radar applications is presented with low insertion loss. Finally, we should mention the new emerging micromachining techniques, which have been applied to the design of waveguide filters [14]. Nevertheless, these micromachining techniques are still not mature to implement components with stringent specifications.

We present here the design of a new waveguide band-pass filters at W-band, which fulfill the challenging specifications for radio-astronomy receivers, namely low-loss, high in-band transmission and high out-of-band rejection. Different electroformed prototypes are presented with low insertion loss. The proposed filters can be used to select the desired spectral band placing it after the horn antenna in an eventual radio-astronomy receiver.

2. Theoretical synthesis and circuit model

The desired filter specifications are summarized in Table 1. Notice that, for such high out-of-band rejection levels, a high-order filter should be synthesized. In this case, an all-pole tenth order filter is required, as will be shown in the following.

The standard synthesis technique based on direct-coupled resonators [15] is applied. The circuit topology is based on direct in-line coupled resonators. In that way, all-pole responses can be implemented. Chebyshev and Butterworth responses are the most used all-pole responses. Chebyshev response was chosen in this case since it leads to the maximum rejection out-of-band for a given equiripple response in the band-pass.

The followed synthesis process can be summarized as:

- First, a low-pass prototype with normalized frequency is synthesized, leading to a LC ladder network [16].
- A low-pass band-pass transformation is applied. In that way, the band-pass circuit elements are obtained. The band-pass circuit is made up of series and parallel resonators [16]. Notice that this is a narrow band transformation, valid for a specific bandwidth close to the center frequency.

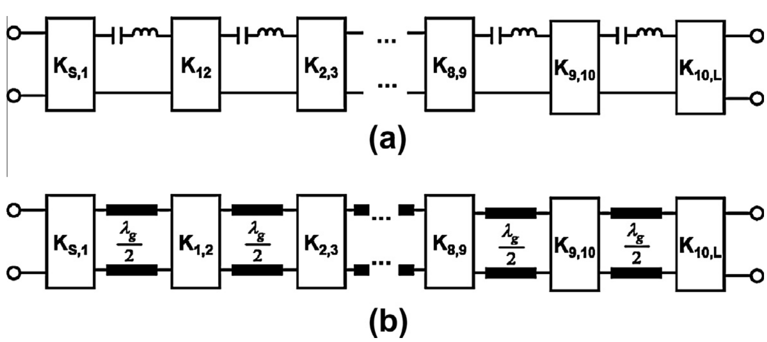
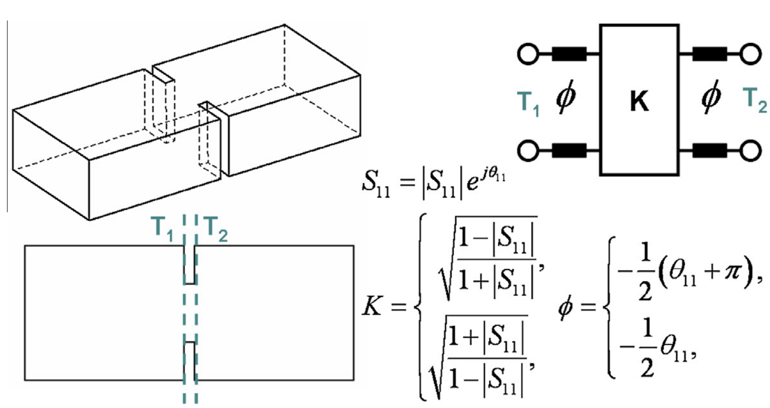


Fig. 1. Equivalent circuit of the synthesized filter: (a) Lumped and (b) Distributed. The inmitance inverters values for the specifications of Table 1 are $K_{s,1} = K_{10,L} = 0.6096$, $K_{1,2} = K_{9,10} = 0.3332$, $K_{2,3} = K_{8,9} = 0.2476$, $K_{3,4} = K_{7,8} = 0.2332$, $K_{4,5} = K_{6,7} = 0.2288$, $K_{5,6} = 0.2277$.



$$S_{11} = |S_{11}| e^{j\theta_{11}}$$

$$K = \begin{cases} \sqrt{\dfrac{1-|S_{11}|}{1+|S_{11}|}}, \\ \sqrt{\dfrac{1+|S_{11}|}{1-|S_{11}|}}, \end{cases} \quad \phi = \begin{cases} -\dfrac{1}{2}(\theta_{11}+\pi), & K<1 \\ -\dfrac{1}{2}\theta_{11}, & K>1 \end{cases}$$

Fig. 2. Equivalent circuit of a thick H-plane iris.